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A Hebridean frost hollow made visible

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Introduction

The Outer Hebrides (or Western Isles) of Scotland (Figure 1) is one of the windiest and most exposed parts of the United Kingdom, and not the first place one usually thinks of when it comes to temperature inversions and frost hollows. However, clear skies and relatively calm weather conditions do present themselves now and again in the Hebridean climate, and the following article uses a combination of two visible photographs and one infra-red image to demonstrate the characteristics of a rather unusual frost hollow located on the Stornoway golf course on the island of Lewis.

Most of the Outer Hebrides is treeless with blanket peat or bog interspersed with small hills and lochs. However, around the coastal fringes of the islands the soil is generally of better quality and this has provided sustenance to small crofting communities for generations. In the vicinity of Stornoway additional fertile soil was imported from overseas as ballast in ships during the nineteenth century for the gardens of Lews Castle, and a rich mixed woodland park was established in the vicinity and remains to the present day. After the end of the Second World War, Stornoway golf course was set up on the northern edge of this estate, just to the north-west of Stornoway town. A large stone wall (1.5–2m in height) marks the lower eastern boundary of the golf course, providing a barrier to the drainage of shallow cold air pools.

Description of the photographs

Figure 2(a) shows the ground frost distribution over Stornoway golf course at 0845 UTC on the morning of 1 December 2009, looking westwards from the bottom of the golf course (about 5m above sea-level (*ASL*)) up towards the crest of Ranol hill (up to 50m ASL), which is the highest point on the golf course. The position at which the author took this photograph is marked on Figure 1 by a

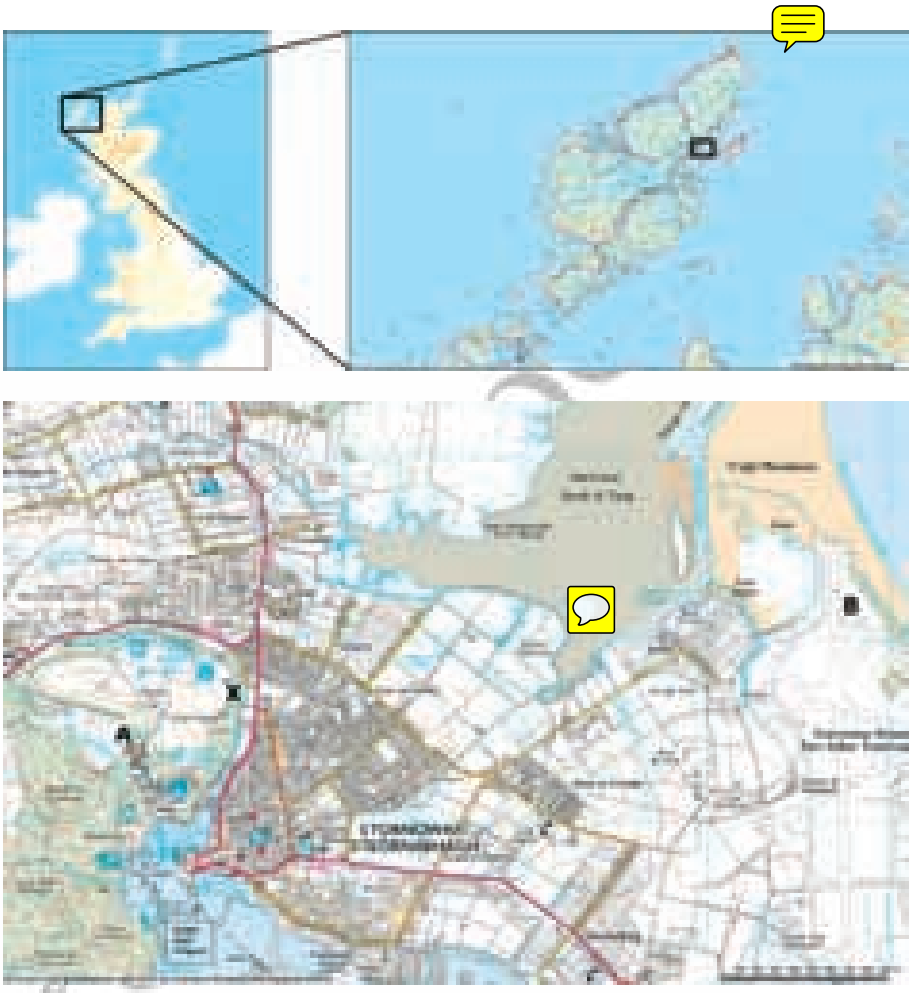

Figure 1. Location of Outer Hebrides (top) and Stornoway town and environs (lower). 'A' marks the site of Lews Castle College weather station, 'B' is the official Met Office Stornoway Airport site, 'X' marks the location at the bottom of Stornoway golf course where the author took the photographs shown in Figure 2(a–c). (© 2011 Crown Copyright/database right. An Ordnance Survey/EDINA supplied service.)

large 'X'. A sharp frost had developed during the previous night (a minimum temperature of –2.9°C was recorded at nearby Lews Castle College), but an increasing southeasterly breeze (and patchy cloud) had already cleared the frost from upper reaches of the golf course by the time the photograph was taken. However, the frost had persisted in the more sheltered environment at the base of the hill (nearer the photographer), yielding an excellent example of frost in a hollow. The sun had not yet risen, so cannot have contributed to the melting of the frost on the hil. A hand-held thermistor (bulb of 2mm diameter and slung in a characteristic 'sling psychrometer' fashion) indicated air temperatures to be close to 0°C in the frosty area, but nearer 3°C on the upper slopes of the golf course shortly afterwards.

Figure 2(b) shows the same view of Stornoway golf course two months later, at 0911 UTC on the (cloudy) morning of 5 February 2010, showing the strange but curious occurrence of snow only on low ground. There had been about five centimetres of even-snow cover over the entire golf course during the previous week, but a thaw had set in on 4 February. The

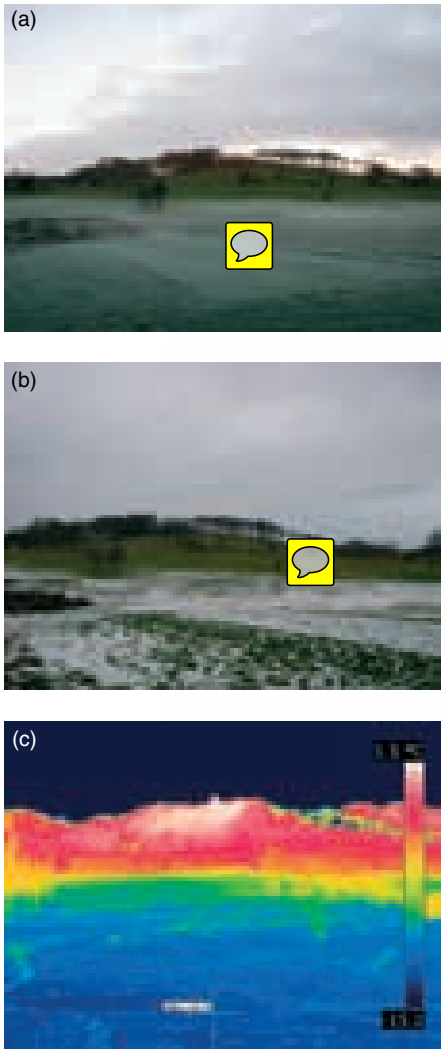

Figure 2. Looking westwards from the foot of Stornoway golf course towards the crest of Ranol hill: (a) Ground frost at 0845 UTC on 1 December 2009. (b) Snow-cover distribution at 0911 UTC on 5 February 2010. (c) An infra-red camera image of temperature distribution at 0913 UTC on 22 December 2010. Note the co-incidence of the extent of the features between the three images: see text for full details. (©2011 Edward Graham.)

combination of stagnant air and lower temperatures within the frost hollow during these few days, as well as a fresher breeze on the higher slopes of the golf course throughout the 4th, are thought to have contributed to the snow remaining only at the bottom of the golf course. As dewpoints rose above zero during the previous day's thaw, it is thought that a combination of rapid convective and latent heat-transfer to the snow cover by the wind would have melted it more quickly on the upper (windier) slopes of the golf course. Note the coincidence between the extent of the remaining snow cover in Figure 2(b) with that of the frost extent in Figure 2(a) two months earlier.

Remarkably, the same phenomenon of snow on low ground only was repeated three weeks later, on 26 February 2010, when a strong northeasterly wind accompanied by an air temperature a few degrees above freezing melted most of the previous weeks' snowfall on the upper reaches of the golf course, but not in the frost hollow for a further day. A further example of snow remaining in the hollow was photographed by the author on 13 January 2011.

During and after these events, a number of pedestrian and bicycle traverses were conducted on ideal radiation evenings, nights and early mornings using portable thermistors. These often revealed temperature differences of 3 degC between the top of Ranol hill and the foot of the golf course, but sometimes, on clear nights with a snow-cover, the difference was greater than 5 degC. Minimum air temperatures measured on the golf course were always several degrees lower than those recorded at the official Stornoway Met Office reporting station, located 4km to the east at Stornoway Airport, which is close to a beach and open sea (Figure 1; see also Strangeways, 2009).

Ten months later, during the severely cold and snowy weather of December 2010, the opportunity arose to use an infra-red camera to monitor the development of the frost hollow on Stornoway golf course on an extreme radiation night. Thus, Figure 2(c) shows an infra-red (IR) image of the same view across the golf course at 0913 UTC (one minute before sunrise) on the morning of 22 December 2010, looking in the same direction (westwards) towards the crest of Ranol hill. The IR camera was operating at wavelengths from 7.5 to 13mm and the presence of the thick uniform snow cover on this occasion (12–15cm in depth) across all of the golf course meant that any temperature differences measured by the IR camera were not caused by differences in surface emissivities, but were due to surface temperature variations alone. As can be seen, the same pattern of a very cold foreground at the bottom of the golf course, with much warmer conditions on the upper slopes and near the trees of Ranol hill, is clearly apparent, although the temperature differences are amplified on this occasion. Assuming a snow emissivity of 1 (Brownscombe and Roach, 1984; Graham, 2004), the IR camera indicated surface temperatures ranging from as low as –15°C in the foreground up to +1.0°C near the treetops at the top of the golf course. The author detected no discernible wind or airflow at the base of the golf course at the time, but there was a gentle northwesterly breeze on Ranol hill shortly afterwards. The same hand-held 2mm-diameter thermistor used in the earlier studies indicated air temperatures of around –8°C in the frost hollow and near 0°C at the top of the hill.

The infra-red camera had also been used the previous night at 2100–2200 UTC at the same location. Whilst the temperatures were not as extreme as measured on the following morning, the surface temperature distribution on the golf course was almost identical to that found then, so the cold pool did not deepen or grow significantly in size during the night nor was there any indication of cold air (katabatic) drainage towards the frost hollow. Indeed, the upper reaches of the golf course appeared to have remained consistently less cold throughout the night with a steady breeze from the northwest preventing significant cooling. This leads to the conclusion that the cold air must have been entirely generated *in situ* within a separate stable boundary-layer of air, albeit only a few metres deep, at the base of the golf course, and was prevented from moving on by the presence of the large boundary wall and nearby trees. These findings are in agreement with earlier frost hollow studies in Ireland by Graham (1992, 1993, 2004).

Summary and conclusions

This article has presented three images which capture the occurrence and make visible the extent of a shallow frost hollow on three separate occasions. The cold air residing in the hollow does not appear to be the product of katabatic downslope airflow, but instead may be entirely locally generated within a separate, stable, but shallow boundary layer.

There are probably thousands of frost hollows of a similar nature across the UK and beyond, of which Chipstead valley (Currie, 2011), Rickmansworth (Galvin, 2004, 2005), Altnaharra (Burt, 1997), La Brevine, Switzerland (MeteoSwiss, 2011) and Hog's hollow, Toronto, Canada (Middleton and Millar, 1936) are just a few of the better known and more explored examples. However, what is probably unique about this Hebridean frost hollow is that it has provided three independent images when the frost hollow has become visible.

Acknowledgments

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AQ4 **Abstract: (•online only)**

This short article presents and discusses two visible photographs and one infra-red image which visibly capture the extent of a local frost hollow on Stornoway golf course in the Outer Hebrides of Scotland. The cold air residing in the hollow appears to be generated *in-situ* within a stable boundary layer, and is not the result of katabatic flow.

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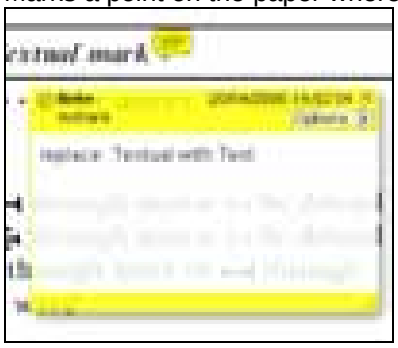

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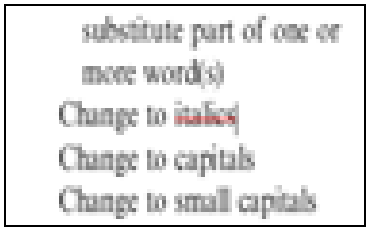

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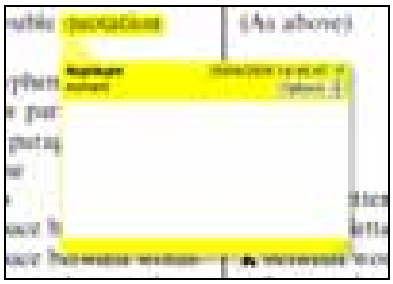

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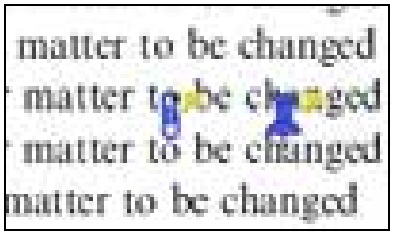

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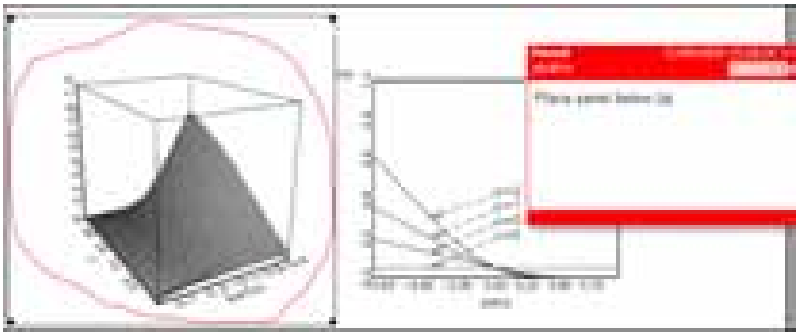

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